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ON UTILITY AND METHODS OF SOIL ANALYSIS.

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It is the object of Agriculture to supply to the world the crude materials of what we eat and wear; or, as more commonly known, Agriculture is the art which pertains to the cultivation of the soil, and to the rearing, feeding, and management of live stock. There is no art more important than Agriculture, nor none which presents so many subjects of scientific inquiry and vital interest. And yet, but few subjects of similar moment, but what have received far more thorough and scientific research. I fancy this is because agricultural science is as yet in its infancy. Other sciences must first be developed before this could make any satisfactory advancement:—Chemistry to give methods of analysis, and Geology to tell of soil formation. Botany and Zöology must also make their contributions, while years of experience, and practical testing of theories should add their corroboratory testimony.

Agriculture takes rank among the highest sciences, but sin-gularly enough, is but lightly appreciated, even by the class of [m]n who should give it the most attention. The farmers, as a [cla]ss, are not sufficiently informed, and among most of the ed-[uc]ated, other subjects are given greater prominence, while [A]griculture receives only a casual consideration. The decay [o]f old empires, and the decline in national vigor of the people [o]f those governments, clearly indicate that the farmer must

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have regard to the manner in which he treats the soil from whence comes his bread; while the statesman should not be ignorant of one of the grandest elements of national prosperity, viz: soil fertility.

The farmers of every age and country have first planted one crop after another, without any regard for the soil's treatment. And quite naturally enough, for they did not know what composed the soil or the plants growing upon it. They did not know how to care for their land, and consequently it soon began to exhibit signs of infertility. The difficulties they could not remedy, but other countries were fertile and to them many of the people emigrated. Men, however, cannot easily migrate, nor are such migrations conducive to national prosperity; hence the leading men of the nation, perceiving the evil, began to give attention to the soil's cultivation. Among the Hebrews the land had its periods of rest. Other and later generations thought of adding something to the soil. But what should be added, and should the same fertilizer be added to all soils?

China and Japan solved the problem quite satisfactorily for themselves. But they shut themselves up from the rest of mankind, and we Indo-Europeans remained in ignorance as the rolling centuries passed along.

A host of fertilizers have been tried and many of them found to improve the soil's fertility. But as the same fertilizer would not answer on different soils, it was with much reason presumed, that a chemical analysis of the soil and of its vegetation, and of the substances to be added would give all the required information for MAINTAINING THE SOIL'S PRODUCTIVENESS.

If we knew what to add to the soil, there seemed to be no question, but that the soil which yielded one bale of cotton to the acre, and which now yields but one-fourth of a bale, would yield, by this new and really marked advance in agricultural knowledge, from two to three bales per acre. Our expectations were high, but our two or three bales of cotton to the acre were rarely realized. What was the difficulty? We certainly are in possession of an important factor in crop culture.

Not every analysis was correct, and no thought was tak as to whether the important soil constituents were in an av able or unavailable condition. A mechanical analysis mus made in addition to the chemical. The physical properties the soil, whether open, light, porous, heavy, dark, deep, or sh low; its dryness, warmth, division; whether in a rainy or rai

less region; climate, high or low land; kinds of crops raised on the soils; how long under cultivation; drainage, etc.; all these factors, and more, are to be taken into consideration. Hence a single chemical analysis, while giving valuable information to the agriculturist, is only one of many things which determine the value of the soil and its adaptation to particular crops.

This fact, however, is generally lost sight of; many giving undue prominence to the soil's chemical analysis, while others, among the number Professor Johnson, consider it as comparatively useless, and urge such objections as the following: Two soils may be of quite similar composition, and yet be very unlike in fertility. The least productive one, is so because of some physical condition: as a want of under-drainage, lack of rain, depth of soil, etc.

To correct the soil's physical defects often improves at once its chemical condition. A correct chemical analysis of the soil requires much time and is expensive; and when made, one is not able to tell whether his soil is just now fertile or barren. Some soils, naturally sterile, by adding four hundred pounds of guano to the acre, manifest a wonderful productiveness. The analysis represents but a small part of the field, and does not indicate the soil's openness, heaviness, etc. Johnson suggests, instead of chemical analysis, experiments on different plots of land with those fertilizers most likely to cause the particular soil to become fertile. These are strong objections against the chemical analyses of soils, if such analyses were one's only source of information respecting the soil's composition, condition, and value. But, when we know that chemical analysis is only one factor of our knowledge of the soil and its intelligent cultivation, the above objections appear a little specious, and thus lose most of their force. Is it not rational to suppose that a soil rich in certain ingredients would be better adapted to a particular class of plants demanding those particular ingredients, than it would be for any other class of plants? To determine by experiment alone what a soil is good for, is, to say the least, a lengthy, tedious, and costly process. In the case of "poison soils," which to all appearances are fertile, and yet contain substances which are injurious to crops, experiment is almost folly. Take this example: some soil of Bae's Island, Beaufort county, South Carolina, appeared to be good soil, but would not grow cotton. The planters did not

know how to obviate the difficulty. They had tried Professor Johnson's blind experiments to their entire satisfaction. The soil was analyzed, and found to contain some proto-sulphate of iron, a substance which is poisonous to plants. The chemist gave the remedy also, viz: under-drainage, aeration, and the addition of some lime.

Comparative Chemical Analysis of Soils not only tells one what is the soil's composition, but also the ratio of its plant ingredients to each other and to those found in other soils.

If a soil is found to be rich in the nutritive plant ingredients, viz: K_2O, P_2O_5, CaO, N and C, we know what crops would, in all probability, grow most successfully upon it; and if deficient in any one of these elements of plant foods, what particular fertilizer could be most advantageously applied. For example: in a soil containing a small proportion of lime and sulphuric acid, let leguminous plants as peas, beans, etc., be planted; this soil would soon give out; but, by the addition of an occasional coat of gypsum, its fertility is maintained. Again, if in a soil, which is poor in phosphates, cereals are planted, we know it will soon become exhausted, and that our remedy is to add to the soil super-phosphates.

These remedies are not infallible ones by any means, and the soil which is rich in K_2O, CaO, P_2O_5, N. and C., may have these compounds in an unavailable form; but we have much light thrown upon the soil's permanent value, and probable adaptation. A soil which is rich in this plant food, will undoubtedly contain much of it in an available form.

By the Mechanical Analysis, and the observations and inquiries made in connection with it, we obtain very much additional knowledge of the soils condition and value. A soil composed mostly of fine silicious silts, and a small per centage of clay, we know is very heavy, will clog to the plough, and cakes when drying. Coarse ingredients make the soil more porous and light. We find that the clay in the soils is the richest in mineral ingredients, holds the most moisture, ammonia and other soluble salts, and its insoluble residue is comparatively small. A soil of coarse sand is infertile, subject to drought, and will not allow plant food to accumulate. A soil of fine sand with some clay is a good one, especially if derived from easily decomposed rocks.

Thus we find, that a chemical and physical analysis of the soils lies at the foundation of a proper estimate of its capacity,

adaptation, and future value. The soil contains the ancestral remains of past ages, and is the great store-house from which we draw most of life's supplies; consequently, a scientific inquiry into its composition and value, is a matter of prime importance: not alone to the farmer, but to the statesman also. Such an inquiry tells us what is in the soil, in what condition, the physical structure of the soil, what crops are best to plant, and what fertilizers to add. Let us now consider the methods of conducting this inquiry.

SELECTING SPECIMENS.

Before commencing the analysis, and at the place of gathering the soil, it is necessary to make note of a few important particulars. 1st. As to the locality; whether hillside or valley land, how near to mountains—in a word, something of the topography of that section. 2d. Underlying geological formation, as well as that from which the soil has been derived. 3d. Depth of soil, surface, and the obvious physical characteristics of the soil. 4th. Local vegetation, natural and cultivated; how long under cultivation, and what crops grown; whether manured, and what manures used; color of soil taken; average rainfall; and any other points of special importance pertaining to that particular locality. To the above information is added the farmer's experience in cultivation of that particular soil.

Sub-soil is preferably taken for analysis, because in surface soils the organic ingredients materially interfere with the operation of the analysis, as well as with the interpretation of its results. The investigation of sub-soils is better calculated to furnish reliable indications of the agricultural peculiarities of extended regions than that of surface soils, which are more liable to local variations, and usually differ from the corresponding subsoils, in about the same general points. The surface soil generally has the largest amount of immediately available plant ingredients, while the sub-soil has the largest supplies for future use. The following table from Prof. Hilgard's Report on the Agriculture of Mississippi, further illustrates their chemical difference.

Analysis of Upland Soil and Sub-soil from Claiborne County, Mississippi.

	Insolu. part.	K_2O.	Na_2O.	CaO.	MgO.	Mn_3O_4.
Surface soil.	87.6	.458	.124	.244	.545	.205
Sub-soil....	79.5	.741	.248	.238	.830	.346

	Fe_2O_3.	Al_2O_3.	P_2O_5.	SO_3.	Volatile matter.
Surface soil.	3.231	4.84	.105	.028	3.073
Sub-soil....	5.634	8.849	.092	trace.	3.476

The specimen for analysis should, whenever possible, be of virgin soil, taken from some one or several spots, carefully selected as correctly representing the average character, undisturbed by local accidents, such as cultivation, roads, gullies, cattle, etc. Make vertical cuts showing distinctly the depth of surface soil and sub-soil, and of each take a specimen of at least 10 pounds, after thoroughly breaking the clods and mixing, with a spade, on a cloth spread on the ground, the pile thrown out of each—the larger the better. A pound or two of the specimen is then air-dried, carefully triturated in a porcelain mortar with a wooden pestle, and sifted through a sieve whose meshes are .8$^{mm.}$ (=.03) diameter. We now have the dry "fine earth"; from this point the two analyses branch.

MECHANICAL ANALYSIS.

We shall first take up the mechanical or silt analysis. Take 15–20 grammes of the steam-dried "fine earth" and boil for twenty-four to thirty hours in distilled water. This is done to completely disintegrate the soil particles. The second process is to separate the clay from the silt and sand, as the presence of clay in the elutriator would materially interfere with the proper separation of the sediments. The clay is thus separated: thoroughly stir the boiled liquid and sediments in a quantity of distilled water, and allow to settle for such a length of time as will allow sediments of .25$^{mm.}$ hydraulic value to subside; the process is repeated with smaller quantities of fresh water until no sensible turbidity remains after allowing due time for subsidence. As some fine silt sediment is poured out with the clay water, and this separation must be repeated, unite the clay waters (4–8 litres), stir them up, allow to settle for eight minutes if the liquid stands at the height of

200^{mm} and then pour off the clay water. The sediments are now ready for the elutriator. The clay water, however, still contains silt of $<0.25^{mm}$ h. v. which is separated by putting the clay water in a cylindrical vessel to the height of 200^{mm}, allowing to subside for twenty-four hours, then decanting the clay water and kneading the silt with a rubber pestle. Fresh distilled water is again added, the whole agitated and allowed to subside for another twenty-four hours. Repeat the operation until the decanted liquid is clear, or fails to become so by the addition of salt water.

The clay is precipitated from the clay water by adding 50 c. c. of saturated brine to each litre of clay water.

Collect the precipitate on a weighed filter, wash with weak brine, dry at 100°C and weigh. The salt in the clay is then washed out with $(NH_4)_2Cl$, and the weight of the salt in the filtrate is determined by evaporation, ignition and weighing. Knowing this weight we can easily determine that of the clay. The amount of clay in the purest natural clays rarely reaches 75 per cent; 40—47 in the heaviest clay soils, and 10—20 in ordinary loams.

Separation of the silt and sand sediments.

These sediments are transferred to the Elutriator, a cylindrical vessel through which water is made to pass, carrying along with it sediments corresponding to the different velocities of water passing through the tube.

The different velocities of the water are determined by means of the graduated arc along which the long arm of the stop-cock moves.

The cylindrical vessel and churner at its base are designed to prevent the aggregation of flocculent masses of sediment which tend to form in the ascending current.

Several other devices intended to accomplish the same result have been resorted to by different persons, as Nöbel's apparatus with its four vessels of ever varying capacity, slope of sides and variable head of pressure. This apparatus gives five different sediments of a character not approaching uniformity. In the same instrument with the same kind of soil, one gets widely different results.

Yet this apparatus is the one recommended by Caldwell in his work on Agricultural Chemistry, and the one used by Emil Wolff of Germany.

Schultze's apparatus as modified by Fresenius, is a tall, conical champagne glass with an adjustable stream of water descending through a tube in the axis. This apparatus is better than Nöbel's but has the defect that heavy sediments collect around the mouth of the tube, thus affecting the velocity of the stream, and allowing a portion of the fine sediments to escape the elutriating action. Dietrich's apparatus is a device for carrying the sediments in a stream of water, under constant pressure, flowing through four tubes of different sizes and inclined at different angles. This apparatus will not give like results with similar soils. The later and more improved methods of Mueller and Schoene give more satisfactory results but have the same defect in common with all the others; viz: no agitation of the sediments by outside power. Prof. Hilgard uses a Mariotte bottle (10 gal.) to get a constant pressure for the different velocities of water; a cylindrical vessel through which the sediments are borne; and a rotary churn by which the sediments are constantly agitated.

From this digression in regard to the various methods employed in making silt analyses, we come back to our mixed sediments. These are cautiously put into the elutriator, and the current adjusted to the lowest velocity to be used; the flow continuing until all sediment of that hydraulic value has passed off, when the higher velocities are successively turned on.

Decant and filter the water from the respective sediments, except those below $.25^{mm.}$, which after subsiding to 25—50 c. c. m. are evaporated in a platinum crucible. The sediments are dried at 100°C and weighed.

Character of the Sediments.

As a standard of size measurement we take the round quartz grain of $\frac{1}{180}$ m. m. diameter. None of the sediments are entirely free from particles of the one next below, owing both to the progressive disintegration of conglomerated particles by the stirrer, and to the inevitable formation of the flocculent aggregates of the finer sediments.

By measuring the sediments and comparing them with our standard we have the following;

Table of diameters and hydraulic values of the different Sediments.

Name.	Diameters.		Velocity per second or Hydraulic value.	
1, Coarse Grits..	1 — 3	mm.	?	
2, Finer Grits....	.5 — 1	do.	?	
3, Coarse Sand..	.80 —90($\frac{1}{180}$)	do.	64	mm.
4, Medium Sand.	.50 —55 "	do.	32	do.
5, Fine Sand....	.25 —30 "	do.	16	do.
6, Finest Sand..	.20 —22 "	do.	8	do.
7, Dust Sand....	.12 —14 "	do.	4	do.
8, Coarsest Silt..	9 — 9 "	do.	2	do.
9, Coarse Silt...	6 — 7 "	do.	1	do.
10, Medium Silt..	4 — 5 "	do.	.5	do.
11, Fine Silt.....	2.5— 3 "	do.	.25	do.
12, Finest Silt....	.1— 2 "	do.	<.25	do.
13, Clay.........	?		<.0023	do.

Strictly speaking, none of the sediments actually correspond to the velocities calculated from the cross section of the tube and the water delivered in a given time, but to higher ones. Still these sediments show at once even to the naked eye, that the assorting process has been quite successful, and that the prominent characteristics of soils in these respects may thus be determined and exhibited to the eye with a very satisfactory degree of accuracy.

I here recall to mind the object of silt analysis: It is to convey to any intelligent mind, anywhere in the world a definite idea of the agricultural qualities of the soil; of its tillability, perviousness, and behaviour in wet and dry seasons; its liability to washing etc.; which will be accomplished as soon as all the physical coefficients belonging to each of these sediments shall be understood.

CHEMICAL ANALYSIS.

Our attention shall now be directed to the chemical analysis. In this part of my analysis, as in the mechanical, I have followed the method employed by Prof. Hilgard:

First: To determine the Hygroscopic Moisture of the soil, a quantity of the fine dry earth is exposed in a thin layer to a saturated atmosphere for twelve hours; weigh and dry at 200°C. and weigh again. The difference in weight gives the percentage of hygroscopic moisture. The object of this determination is to ascertain the soil's power to resist drought.

For the general analysis, take 2 to 2.5 grammes of the dry soil, and digest in HCl of strength 1.115 over a water bath for five days; evaporate, moisten with HCl, redissolve in distilled water, and filter. The filtrate contains the substances for which we are looking, viz: K_2O, Na_2O, CaO, MgO, Fe_2O_3 Al_2O_3 and SO_3. The author of an article in the New American Cyclopedia and Dr. McMurtrie in Agricultural report for 1873 (also Mr. Grandeau) object to the use of HCl to dissolve out the available plant ingredients, saying that we go farther than the forces of nature. They would digest the soil with $(NH_4)_2CO_3$.

NH_4 and CO_2 act to set free the alkalies in soils. Lime has a similar property. In the soil we find humic, ulmic, crenic, apocrenic, sulphuric, and oxalic acids. Different plants have different acids to exert their solvent action on the soil ingredients. So one finds that $(NH_4)_2CO_3$ is only one of several soil solvents—a strong one to be sure, yet it does not give us in solution all the available plant ingredients of the soil. HCl does, being the best single acid for dissolving inorganic substances. Should one get much more of the plant ingredients by using HCl than is at once available to the plant, he is safe, at least for comparative analyses, and also knows what may be useful in future to the plant.

So far as we know at this time, no one solvent is adequate to make the distinction between available and unavailable soil ingredients for all crops. The comparison of soils of similar origin, analyzed in a similar manner, is the best we can do at present. When we thus ascertain that a soil is rich in nutritive ingredients, we know that for durability, it is preferable to others of its kind containing a smaller proportion of the same ingredients.

In the insoluble residue the soluble silica is determined by boiling in Na_2CO_3. The Fe_2O_3 and Al_2O_3 are precipitated according to Rose's method of boiling with $(NH_4)HO$ and (NH_4) Cl. The mixed precipitate is treated with KHO. Precitate the CaO by $(NH_4)_2O_4$ and destroy the ammoniacal salts by Lawrence Smith's method with aqua regia: and the residue is converted into nitrates, from which SO_3 is precipitated by $Ba(NO_3)_2$ The alkalies are then separated by treatment with oxalic acid; ignite, dissolve in water and filter. In the residue, Ba, Mn, and Mg are separated as usual. The alkaline carbonates are converted into chlorides and K precipitated by $PtCl_4$; evaporate and dis-

solve the Na_2 salt by the alcohol-ether mixture, filter, ignite, and weigh. The Na_2O is determined by difference.

Phosphoric acid determination.

Take 3 to 3.5 grms. of dry fine earth, ignite and digest for five days in HNO_3 over a water bath, evaporate to dryness, moisten with HNO_3, add water and filter; precipitate by ammonium molybdate, filter and dissolve by $(NH_4)HO$; reprecipitate by $MgSO_4$, dry, ignite and weigh as $Mg_2P_2O_7$, from which the P_2O_5 is easily calculated.

The usual mineral ingredients in the soil are, K, Na, Ca, Mg, Mn, Fe, Al and Si, as metallic elements; and P, F, C, S, and Cl as non-metallics. Preëminently the most important of these, and the ones requiring replacement in future by fertilizers, are K_2O, CaO, P_2O_5, N and C.

The phosphates are found chiefly in the seeds, especially of cereals; while root crops draw more upon the K_2O of the soil, and leguminous plants draw largely upon N, and the phosphates. CaO and MgO are preëminently stem ingredients. Na, Si, Mn, Mg, Fe, S, and Cl are generally found in sufficient quantities, and need no replacement. N and C are contained in humus, which may be supplied by green-manuring. Ca, by adding lime, which also sets free unavailable K_2O and other alkalies. P_2O_5 is supplied, when needed, by bone phosphates.

The grand law of soil preservation is to return to the soil as far as possible all that you take from it. Other expedients may be resorted to with great advantage, and in some instances are absolutely necessary to insure a good crop; as subsoiling, green-manuring, underdrainage, mulching, and rotation of crops.

Briefly adverting to my analysis, I give below a succint statement of its

RESULTS.

First: observations made at the place of procuring soil specimen. The sample which I selected for analysis, was some subsoil near the propagating house.* I find it to be a hillside soil of *adobe* character—surface soil one foot deep—subsoil is of light, yellow color, and has the appearance of containing much clay; natural growth—oaks. The soil is derived from the decomposition of coarse and soft clayey sandstone, together with washings from the hill.

Second, I give in a tabular form the results of the mechanical and chemical analyses.

* On the University Grounds.

Table of Mechanical Analysis.

	GRAMMES.
Amount taken for Analysis	19.34
	PER CENT.
(Hygroscopic Moisture	9.07)
Clay	24.7
Sediment of <0.25 m. m., i. e. finest silt	24.5
" .25 m. m.—2 m.m., i. e. remaining silt	11.0
" 4 m. m. i. e. Dust Sand	6.3
" 8 " " Finest sand	5.3
" 16 " " Fine sand	6.2
" 24 " " Medium sand	6.0
" > 24 " " Coarse and medium sand	8.9

Table of Chemical Analysis.

	GRAMMES.
Amount taken for Analysis	2.467
	PER CENT.
Insoluble Residue	80.79
(SiO_2 soluble	5.01)
K_2O	.65
Na_2O	.05
CaO	.35
MgO	.50
Mn_3O_4	.22
Fe_2O_3	5.50
Al_2O_3 (By diff.)	6.43
P_2O_5	.09
SO_3	.10
Water and volatile matter	5.32

My analysis may simply be regarded as a preliminary one. The first analysis is generally considered as one giving valuable suggestions only, to be made use of in a second analysis of the soil, and also indicating much real information as to the soil's chemical and physical composition.

I could not have hoped to have obtained more than approximate results; since in the mechanical analysis, the elutriator which I used is the one designed for coarse sediments only, and in consequence of its conical form, it admits of the formation of return currents, which cause the single grains of sediment to aggregate into heavy masses.

And in the chemical analysis, the chemicals which I used

were not as pure as they should have been, nor was I as successful in the use of them as I might have desired. However, uniting the observations made at the locality where I obtained my specimen, with the results of the physical and chemical analyses, one may arrive at satisfactory conclusions for an approximate analysis.

Making use of my results, then, as the basis of my observations in reference to this soil, I should say, from the chemical analysis, that the soil contains, as most clay soils do, a large amount of K_2O, but a small amount of lime; which indicates that much of the K is in an unavailable form. Hence in all probability the productiveness would be greatly increased by the application of lime.

The consideration of the mechanical analysis shows, moreover that even a small addition of lime would be of advantage in improving the tillable qualities of this soil, since the clay percentage is not very large. Hence in this double point of view, the application of lime is indicated as likely to be of especial advantage to this soil.

We may confidently say that by properly combining the examination of the physical and chemical properties of soil and clays we shall be able to fulfill in great measure the high expectations entertained in the early days of agricultural chemistry.

As furnishing knowledge of the soil, soil analysis is of prime importance and is at the foundation of all agricultural operations. One cannot have a satisfactory or sufficient knowledge of his soil until he has had it carefully analyzed. Uniting the information so derived with that obtained by his own or other's observations,experiments, and experiences,the farmer can then, and only then, intelligently cultivate his soil.